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2.1 A conceptual sustainable domain value stream mapping framework for manufacturing

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Abstract
Adoption of lean manufacturing generally involves waste reduction and its adoption has been successful in improving companies. With increasing awareness on the need for sustainable development, works have been done on sustainability assessment of product design and manufacturing processes. The sustainable manufacturing, 6R method can be adopted to improve the existing design and manufacturing sustainability scores. A conceptual hybrid framework integrating lean manufacturing with sustainable manufacturing theories has been developed thus enabling the benefits from both techniques to be gained. Specifically, the lean manufacturing, value stream mapping tool is integrated with the sustainable manufacturing, 6R method to assist in solving manufacturing problems at process and or plant level sustainably. An indicator, providing the sustainability scores on value adding and non value adding elements at present and future state, has been proposed as part of the framework.
Keywords: Lean Manufacturing, Value Stream Mapping and Sustainable Manufacturing.

1 INTRODUCTION

Manufacturing has become the backbone of a nation's social and economic growth and an enabler for improved standard of living [1]. Sustainable development is the fundamental element in sustainable manufacturing. Sustainable development is supported by three pillars, viz. economic, environment and social. The United Nations' Brundtland Commission (1987) defines sustainable development as:

"*Development that meets the needs of the present without compromising the ability of future generation to meet their own needs*".

The Brundtland definition is fundamentally in line with sustainable manufacturing. The natural resources which the earth provides in the form of raw materials used for manufacturing products are finite and non renewable. Depletion of these raw materials through unsustainable practices will cause hardship to the manufacturing community. The manufacturing sector despite its positive contribution to development produces industrial wastes which pollute the environment. Thus, sustainable development concept has been seen to provide a solution for environmental impact. Sustainability improves societal standard and enhances the availability of resources and ecosystem for current and future generation needs [2]. The motivation for the development of this sustainable domain value stream (SdVSM) framework is to overcome the critics of lean manufacturing. The critics lamented that lean manufacturing place less emphasis on human factor or societal lagging and it is shop floor based [3]. Hence by integrating the sustainable triple bottom line pillars, lean will cover all aspects viz. societal, economical and environment waste.

2 SUSTAINABLE MANUFACTURING

Manufacturing invariably involves a business which involves products that have been produced based on some market demand. In any business there is a need to be competitive in order to gain more market share. By adopting sustainability, an organization will gain competitive advantage which enhances its survival [4]. By employing sustainability, environmental related issues will be prevented thereby reducing the product cost [5]. Sustainability is a cross over between the environment and product design [6]. Sustainable manufacturing paradigm introduces environment concerns in product design stage [7]. An environment conscious product improves product quality and market share [8]. Figure 1 shows the evolution of sustainable manufacturing over time. The stakeholders' value and involvement increases with the evolution and innovation [9]. Sustainable manufacturing at the system level is viewed as the multiple life cycle of the entire supply chain. The life cycle stages are categorized as pre manufacture, manufacture, use and post use phase [10]. On the other hand, [11] has broken the product life cycle into five stages: Pre manufacture, manufacture, product delivery, use and recycle. There was a need for the evolution from 3R to 6R methodology at product level so as to enable the migration of the product life cycle from an open loop to close loop and with multiple life cycle [11]. At the process level in order to achieve sustainable manufacturing, the technological improvements and process planning are the key drivers for reducing resource consumption, energy consumed, waste and environmental impacts [12]. Lean tools are used to solve manufacturing problems in a company [13]. Fusing lean manufacturing technique and sustainable development will improve quality, reduced cost, reduced delivery lead time and improve customer satisfaction [14].

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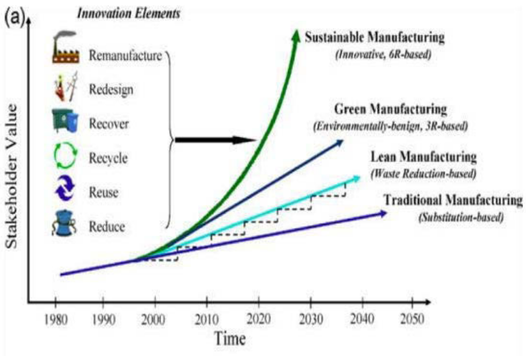

Figure 1: Evolution of sustainable manufacturing [9]

In lean manufacturing, a continuous identification and elimination of waste in the process is the primary philosophy. Eiji Toyoda and Taiichi Ohno developed this lean approach in 1950s and 1960s at Toyota [15]. A waste in a process is defined as other than the minimum amount or quantity required for equipment, parts, materials and working hours in a production or process [16]. Taiichi Ohno had defined seven common forms of waste. This waste purely contributes to the cost but no value. Polarization of resources was introduced as an eighth waste. A conceptual resource mapping framework was applied for polarization resource waste. The polarization meant here was by aligning the resources to maximize value adding contribution [17]. List of Ohno waste [18] and [17], as the eighth waste; production of goods that not yet ordered, waiting, rectification mistakes, excess movement, transport, excess stock and polarization resources.

Value in products is defined as the premium that customer is willing to pay for [15]. In any value stream of manufacturing, an approximate 5% is value adding activities, 35% are non value adding but necessary and 60% non value adding at all [16]. Reference [19] classified the values in internal manufacturing as value adding (VA), necessary non value adding (NNVA) and non value adding (NVA).

The value stream mapping has seven types of tool. Table 1 shows the seven types of value stream mapping tools and its usefulness [20]. Value stream mapping is a lean tool which involves a paper and pencil tool with fixed icons that is a cheap and easy to use [21].

A value stream mapping provides a visualization of the material and information flow in the company and or even supplies chain, thus facilitating decision making to improve the value stream [22]. Traditional value stream mapping improvements are accomplished by employing lean tools. Sustainable indicators comprised of triple bottom line where economical, environmental and societal impacts measured. Indicator is "*a measurement or aggregation of measures from which conclusions on the phenomenon of interest can be inferred*" [23]. The Sustainable Measures Group has established the criteria for the indicator [24]. The criteria are measurable, relevant, reliable, accessible, timely manner and long time oriented. Fulfilling the indicator criteria will ensure accurate data, appropriate decision making and ease representation in qualitative or quantitative. Table 2 provides a summary of literature on various sustainable indicators.

3 SUSTAINABLE DOMAIN VALUE STREAM MAPPING CONCEPTUAL FRAMEWORK

Sustainable Domain Value Stream Mapping (SdVSM) conceptual framework is the integration between lean manufacturing and value stream mapping tool [20] with innovative 6R sustainable manufacturing methodology [25]. Part of the framework consists of visualizing the sustainable indicators based on sustainable scoring method. The framework has two dimensions, first is the lean manufacturing dimension. Here a modified value stream mapping was used to identify the waste in the manufacturing system. In value stream mapping there are seven types of tools and in this model the process activity mapping will the tool. Process activity mapping tool is the simplest tool used to map any process into activities. This tool is easily applied to process, plant or product level.

The second dimension is the sustainable manufacturing element. In this element, 6R methods have been used as tool; reduce, reuse, recycle, recover, redesign and remanufacture.

Table 1: Seven value stream mapping tool with usefulness [20]

Seven Stream Mapping Tools	High Correlation and Usefulness in Waste (Ohno)
Process Activity Mapping	Waiting, Transport, Inappropriate processing and unnecessary motion
Supply Chain Response Matrix	Waiting and unnecessary inventory
Production Variety Funnel	Inappropriate processing and unnecessary inventory
Quality Filter Mapping	Defects
Demand Amplification Mapping	Unnecessary inventory and overall structure
Decision Point Analysis	Overproduction
Physical Structure (a) volume, (b) value	Overall structure

Table 2: Literature on various sustainable indicators [23]

No.	Sustainable Indicators	Summary
1	Global Report Initiative (GRI)	Organization level reporting that covers sustainable development three dimension pillars.
2	Dow Jones Sustainability Indexes (DJSI)	Only top ten percent of companies that is listed in Dow Jones Global Total Stock Market Index. It is a financial and sustainable assessment for investment.
3	2005 Environmental Sustainability Indicator (ESI)	A country or region level environmental evaluation developed by Yale University.
4	Environment Performance Index (EPfI)	Measures the environment stress at country level and complement the ESI. Developed by Yale University.
5	United Nations Indicators of Sustainable Development (UN CSD)	Evaluate the degree of sustainability in a country or regional level.
6	Organization for Economic Cooperation and Development (OECD) core environmental indicator (ECI)	Monitors sustainability indicators of a country.
7	Ford Product Sustainability Index (Ford PSI)	Specialized to automobile manufacturing and service.
8	International Organization for Standardization (ISO) Environmental Performance Evaluation (EPE) standard (ISO 14031)	Specifically covers environmental indicators.
9	Environmental Pressure Indication for European Union (EPrI)	Assessing human activities that given environmental impact.
10	Japan National Institute of Science and Technology (NISTEP)	Indicators that counts the sustainable technological advancement.
11	European Environmental Agency Core Set Indicators (EEA-CSI)	Environment improvement indicators for European Countries.

Reduce refers to first three stages of product life cycles and attempts are made to reduce the use of resources, materials and energy at pre-manufacturing and manufacturing and reduce the waste generated at the use stage [25]. The reuse method is accomplished by reusing the material and energy of a product or component from the first product life cycle to the next life cycle. This method minimizes the usage of raw material for the same product. Recycle is a process of transformation of product at the end of life cycle to a new product. This saves the product to be sent to landfill. The recover is a method of recollecting the used or end of life product and then to be sent for disassemble and cleaned for the next process or life cycle. Redesign where products are simplified at design stage for sustainability for example the concept of design for environment (DfEnv) or design for sustainability (DfS). The sixth R is remanufacturing where the process involves re-processing used product to its original state of design. This is accomplished by reusing the sub parts and parts without loss of functionality of the entire product.

The authors have developed a conceptual framework; see Figure 3 for the SdVSM framework matrix. The entire conceptual framework has tangible and intangible components. The intangible component is the ideology of the framework structure whereby the user will be guided by a series of flow chart type instructions for implementation. The tangible part of the framework consists of a visual sustainability score indicator. This indicator is visualization schematic that gathers sustainability parameters and generates sustainable scores for value adding (VA) and non value adding (NVA). The ideology and visual schematic are driven by SMMIAI methodology for sustainable manufacturing. SMMIAI consists of seven steps of action. Each step has its own define function that requires different

Table 3: SdVSM Conceptual Framework Matrix.

SMMIAI METHODOLOGY	SUSTAINABILITY PILLARS		
	Social	Environmental	Economical
Select	Select study domain at plant level or department level.		
Map	Map the activities using Sustainable domain value stream mapping tool (SdVSM). At this stage VA and NVA activities will be identified.		
Measure	Measure the associated parameter of activities and compute sustainability scores based on SMIR 2013. Sustainable score will quantify the value adding and non value adding activities.		
Improve	Improve problem area viz. activities with low sustainable scores and as well as NVA activities.		
Analyze	Analyze the before and after sustainable scores across the activities after 6 R improvement.		
Indicate	Indicate graphically the before and after improvement sustainability score for value adding and non value adding activities using SdVSM		

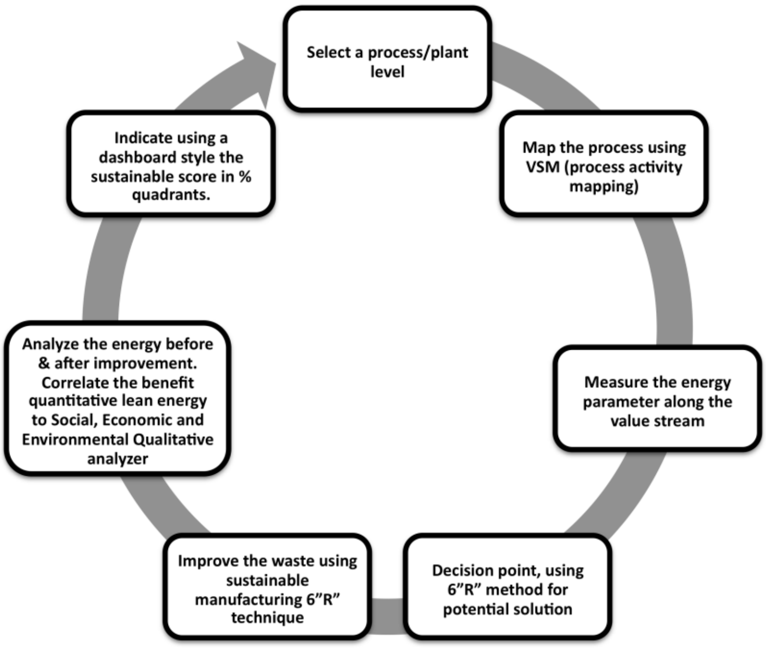

Figure 4: SMMIAI workflow for Sustainable Domain Value Stream Mapping

methods or skills. Figure 4 provides an illustration of the workflow in a simplified manner. In conventional value stream framework, time will be the domain of performance measurement. The lean component will be the value adding and non value adding activities embedded in the value stream [19]. In the conceptual SdVSM framework, time is no longer a domain for measure in the value stream. The sustainable pillars will be the domains. Each activity in the value stream will be measured in sustainable score. For example electrical energy consumption of a process will be measured as the ratio of electrical energy consumed for value adding over electrical energy consumed non value adding. This ratio will be average out from sustainability pillar component.

This framework will evaluate and indicate the sustainable scores on the value adding and non value adding activities in the manufacturing and or in the supply chain. The non value adding activities are considered as waste in the system. Hence the waste is now broken down using triple bottom line sustainable categories, which is societal, impact, economical impact and environmental impact [26]. Equation 1 shows the summation of sustainability score for value adding (Sva) activities and Equation 2 shows the sum of sustainability score for non value adding (Snva) activities. This non value adding activities will be the target for improvement using the 6 R innovative methodologies. In this framework since it inherit the value stream mapping characteristic thus present state and future state can be developed. In this framework the authors used the process activity mapping as the value stream mapping tool. Figure 5 shows the SdVSM sustainable score indicator by activities using process activity mapping.

Sustainability Score in SdVSM

Activities	A	B	C	D	E	F	G	F	Average
s va	0.8	0	0.5	0.7	0	0.2	0	0.8	0.6
S nva	0	0.3	0	0	0.6	0	0.4	0	0.43333333

Figure 5: SdVSM framework Indicator Phase for Visualization (fictitious values given).

$$\sum_{i=1}^{n} Sva = \sum_{i=1}^{n} (social + economical + environmental) \forall \in VA \quad (1)$$

$$\sum_{j=1}^{m} Snva = \sum_{j=1}^{m} (social + economical + environmental) \forall \in NVA \quad (2)$$

Hence low sustainable scores are the potential areas to be improved using the 6R innovative improvement agent. In this framework, 6R method used on process improvement where traditionally used on product and product life cycle. The sustainable metrics are referred to Sustainable Manufacturing Indicators Repository (SMIR 2013) from National Institute of Standards and Technology (NIST) United States of America. SMIR 2011 contains 212 total sustainable indicators [23]. See Table 3 for NIST sustainable manufacturing indicator categorization and sub categories. Table 3 will be general guide for sustainability metrics on the mapped value stream.
In order to determine the level of achievement of the framework a benchmarking will be used for improvement evaluation. Methods of obtaining benchmark values are from the past performance data from the company, standards and set goals for amount of reduction within given time frame [23]. After improvement the sustainable score will be re calculated to indicate before and after scores.

Table 4: NIST Sustainable manufacturing indicator repository [23]

SUSTAINABILITY ELEMENTS	SUSTAINABILITY PARAMETERS	REMARKS
Environmental	Emission	Solid waste emission, air emission, waste energy emission
	Pollution	Hazard substance, Green House Gases, Ozone depleting gases.
	Resource Consumption	Water used Material used (Overall, virgin, reuse, remanufactured, recycled and other material) Energy consumption (Total energy consumed, Renewable energy consumed, Non renewable energy consumed) Land used
	Natural habitat conservation	Bio diversity, habitat management and conservation.
Economical	Costs	Manufacturing cost, material acquisition cost, production cost, product transfer to customer cost, end of life product handling cost.
	Profit	Profit earned by the organization
	Investment	Eco friendly investment
Social	Employee	Health and safety Professional development Employee satisfaction
	Customer	Health and safety of the product at use phase Customer satisfaction with the product Customer rights
	Community	Product responsibility (Justice, Community development program, Fairness, Equity, Human rights, Corruption) Development (Public service policy) Population

4 CONCLUSION

This conceptual framework has advantages over lean manufacturing because lean focuses on operational metrics and by integrating with the triple bottom line sustainability pillars the human factor, costing and environmental issues were taken into account. The second differences from the traditional value stream mapping where takt time, cycle time and waiting were the domain. However in this conceptual framework the triple bottom line of economical, environmental and societal will be the domain across the value stream. A radical improvement tool is used which is the innovative 6 R methodology, where by the 6 R method which was commonly applied at the product level but here it is used for process level improvement. In contrast to the conventional method of improvement in value stream mapping is through the use of lean tools. The framework indicators are representation of sustainability scores of value adding and non value adding activities. Thus decision and improvement affects directly the sustainability level in the chain of activities. This paper introduces the sustainable domain value stream mapping (SdVSM) framework as a conceptual framework and will be tested in a case study to validate it as an operational framework. There is high industrial potential of this framework is due to its simplicity and ability to be applied on the process level whether it is an open loop and close loop manufacturing process activity chains.

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